

HVOF as a Hard Chrome Replacement



Jon L. Devereaux

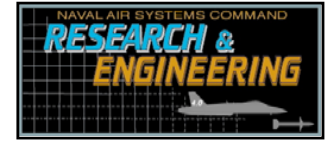
AIR - 4.9.7.4

**NADEP Jacksonville
Materials Engineer**

Report Documentation Page				Form Approved OMB No. 0704-0188	
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HVOF as a Hard Chrome Replacement



Current Status of P-3 Main Landing Gear

**HVOF MLG Piston installed 26 April 99 on VP-30
Aircraft BuNo 156522**

Aircraft completed PDM at NADEP JAX on 5 Dec 99

PDM extended due to multiple spar cap insertions

850 Landings on HVOF coated MLG Piston (Aug 00)

**HVOF Coated Piston removed from service Aug 00 due
to internal oil leak on ID-2 (NOT HVOF COATED)**

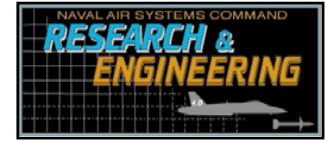
HVOF Coated Strut repaired, sent back to VP-30

Installed on Aircraft 160284 STBD April 25, 2001

1,078 Total Landings on HVOF coated strut (8/23/01)



HVOF as a Hard Chrome Replacement



Current Status of P-3 Main Landing Gear

2,858 Total Landings on HVOF coated strut as of 30 Sept 03

Aircraft sent to Depot JAX for PDM on 13 August 2003

Aircraft returned to VP-30 on Feb. 6, 2004

471 Landings on HVOF coated strut since 2/6 (May 7)

3,329 Total Landings on HVOF coated strut as of 7 May 04

100 Landings on HVOF coated strut since May 7

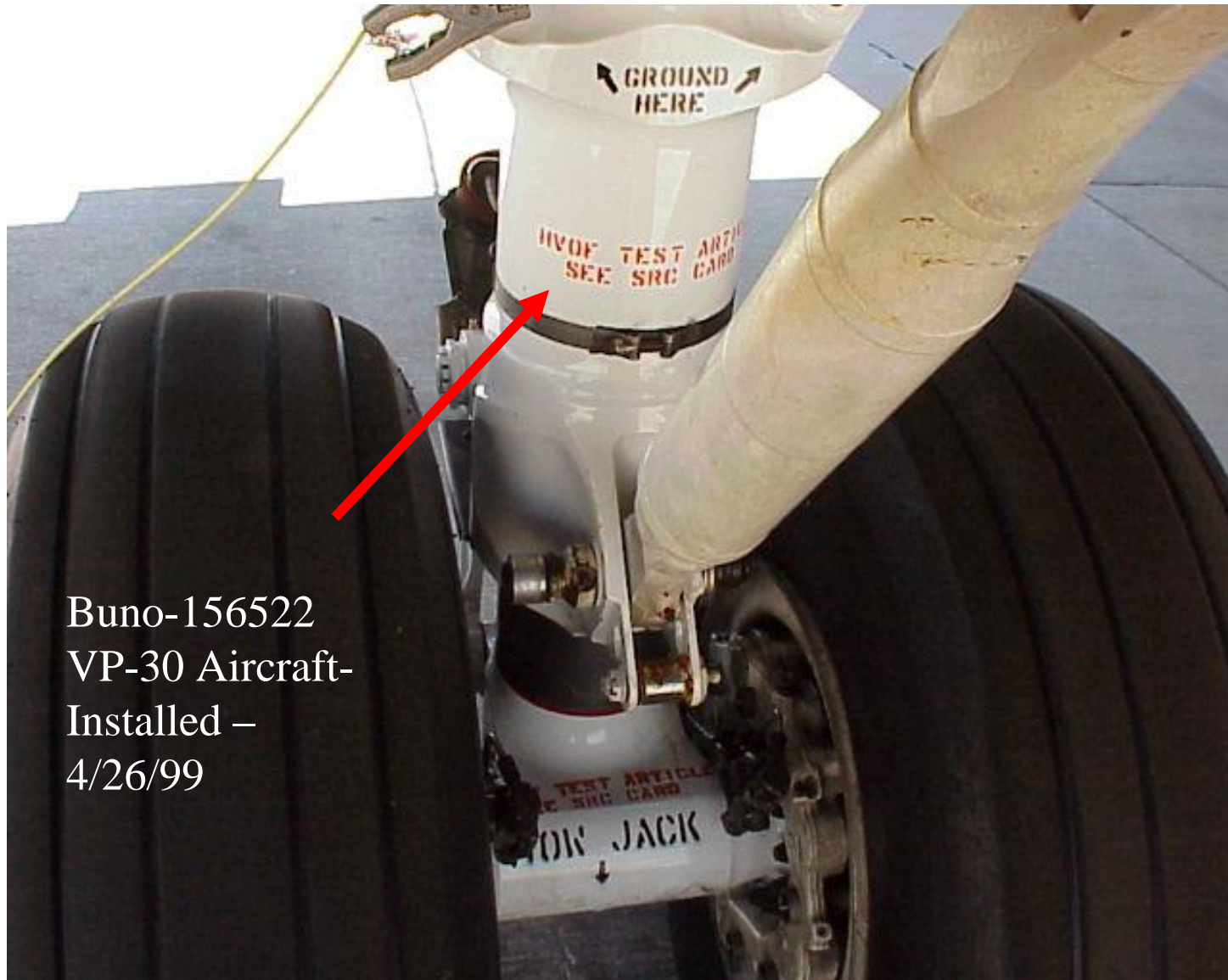
**3,429 Total Landings on HVOF coated strut
as of 9 July 04**

HVOF as a Hard Chrome Replacement



Buno-156522
VP-30 Aircraft
Installed 4/26/99

HVOF as a Hard Chrome Replacement

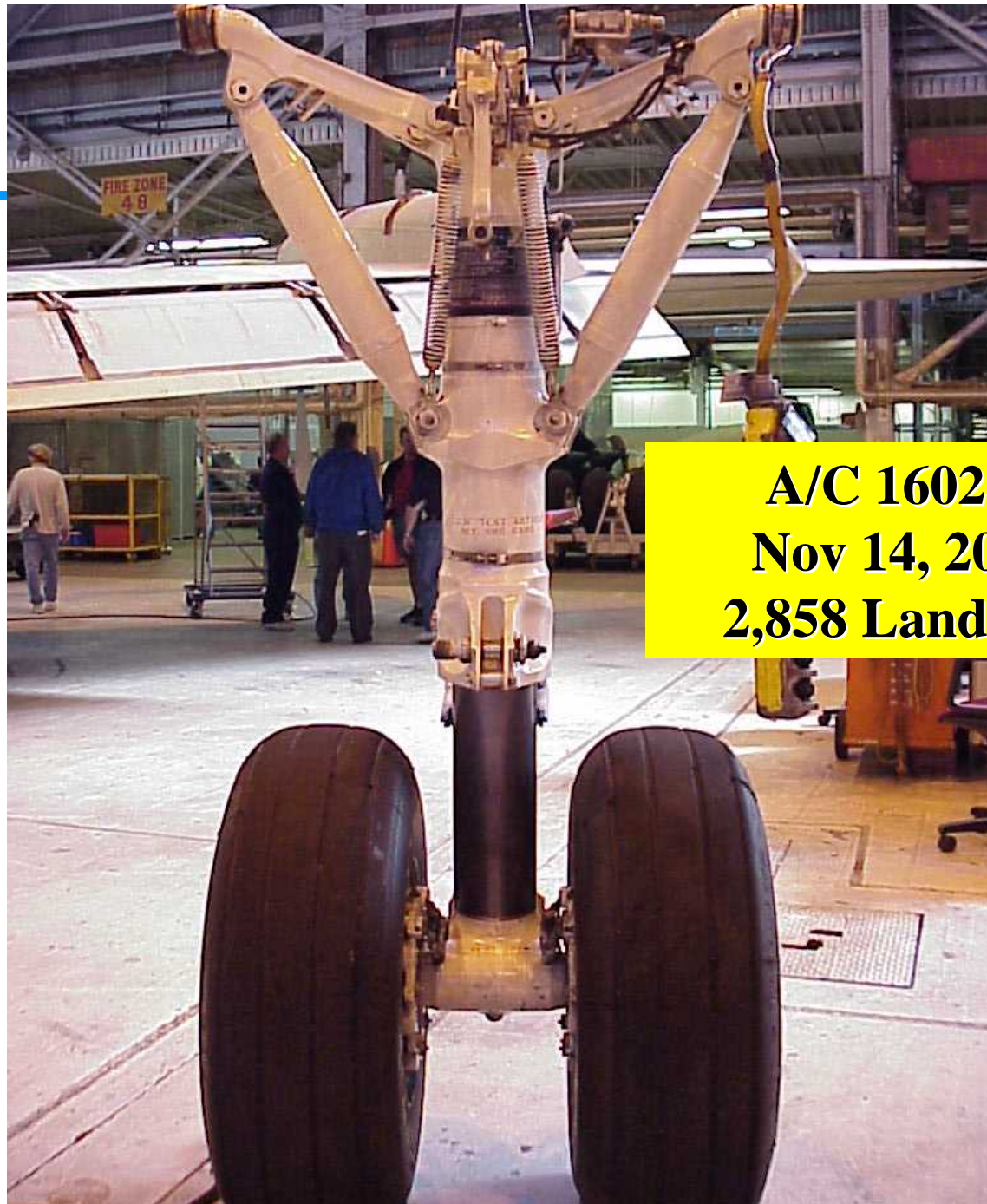


Buno-156522
VP-30 Aircraft-
Installed –
4/26/99

HVOF as a Hard Chrome Replacement

A/C 160284
Nov 14, 2003
2,858 Landings





A/C 160284
Nov 14, 2003
2,858 Landings

HVOF as a Hard Chrome Replacement

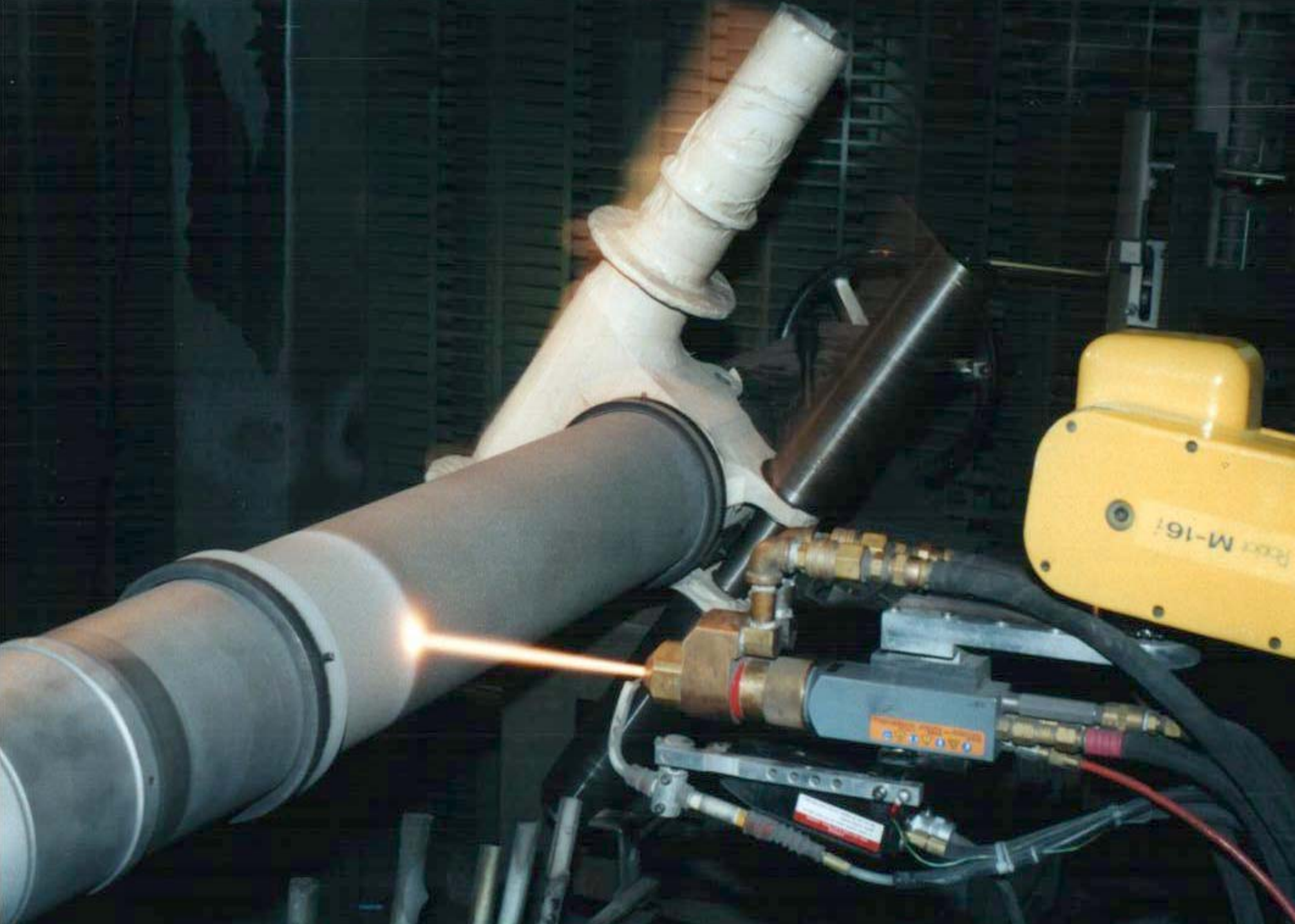
Second P-3 MLG Piston coated with HVOF WC/Co 83/17

- **To be used in \$70M P-3 aircraft SLAP/SLEP - Full Scale Fatigue Test**
- **R/H MLG chrome plated**
- **L/H MLG HVOF coated**
- **HVOF coating, grinding & processing of gear funded by Naval Research Lab (NRL)**
- **Testing started 30 August 2001 (24 month test)**
- **16,000 Cyclic Test Hrs. accumulated as of 30 Aug. 02**
- **Test down since April '02 for repairs; hope to be up Sept. 02**
- **26,000 CTH planned; ECD December 02 if all goes well**
- **Landing gear shows no sign of coating problems**

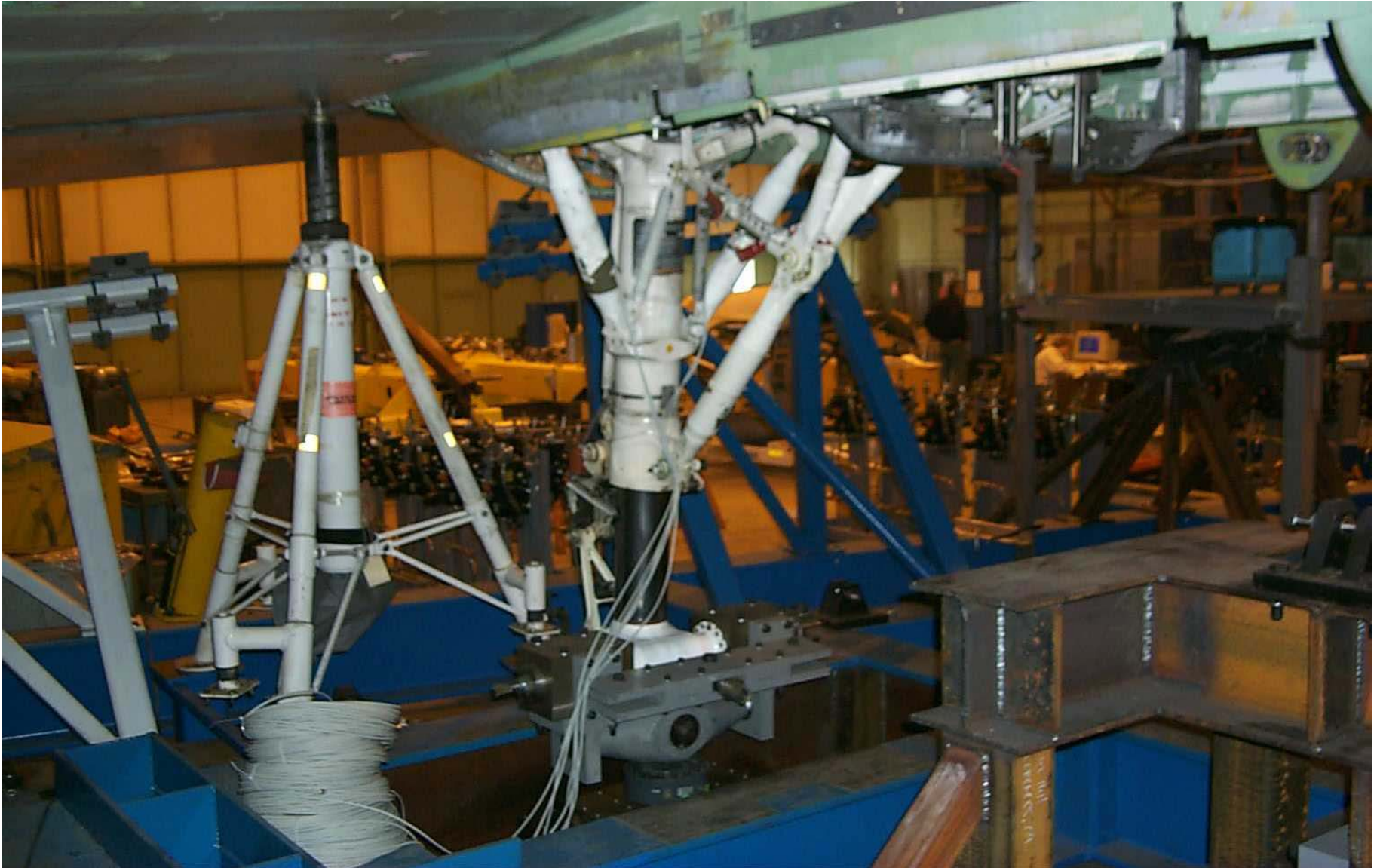
HVOF as a Hard Chrome Replacement

Second P-3 MLG Piston coated with HVOF WC/Co 83/17

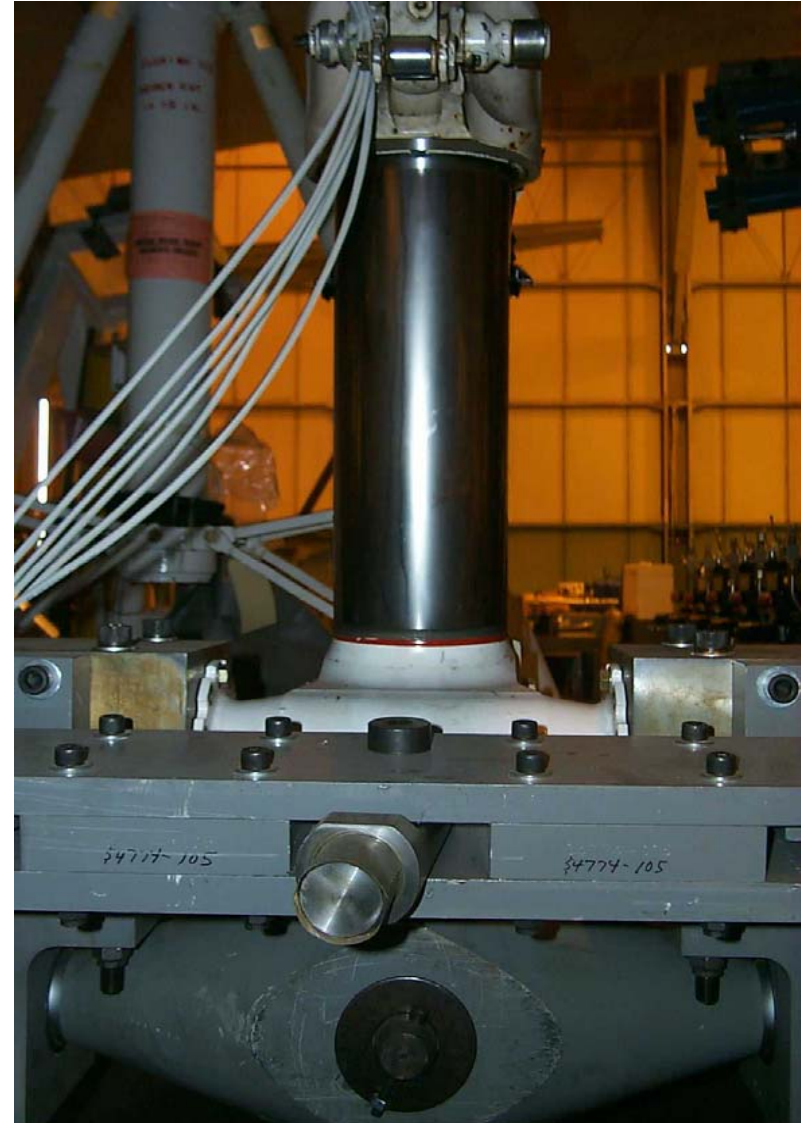
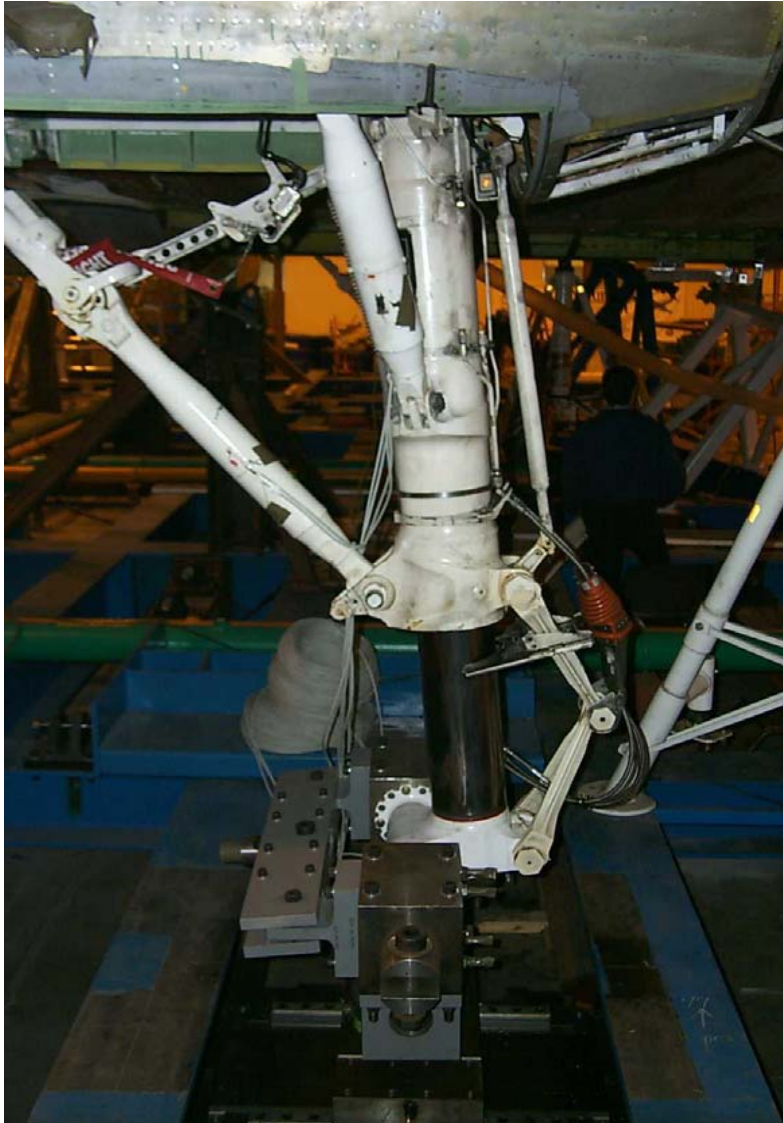
- 26,000 CTH initially planned
- Test extended to 38,000 CTH - some of airframe not tested sufficiently
- 200-250K cycles on LG representing 47,000 Landings
- Test represents two fatigue lifetimes
- If this testing doesn't break the landing gear or HVOF coating, then nothing will!
- Landing gear shows no sign of failure or coating problems
- Test Completed with a "BANG!" on 4 March 2003
- Landing Gear removed April 2003 for inspection



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HVOF as a Hard Chrome Replacement



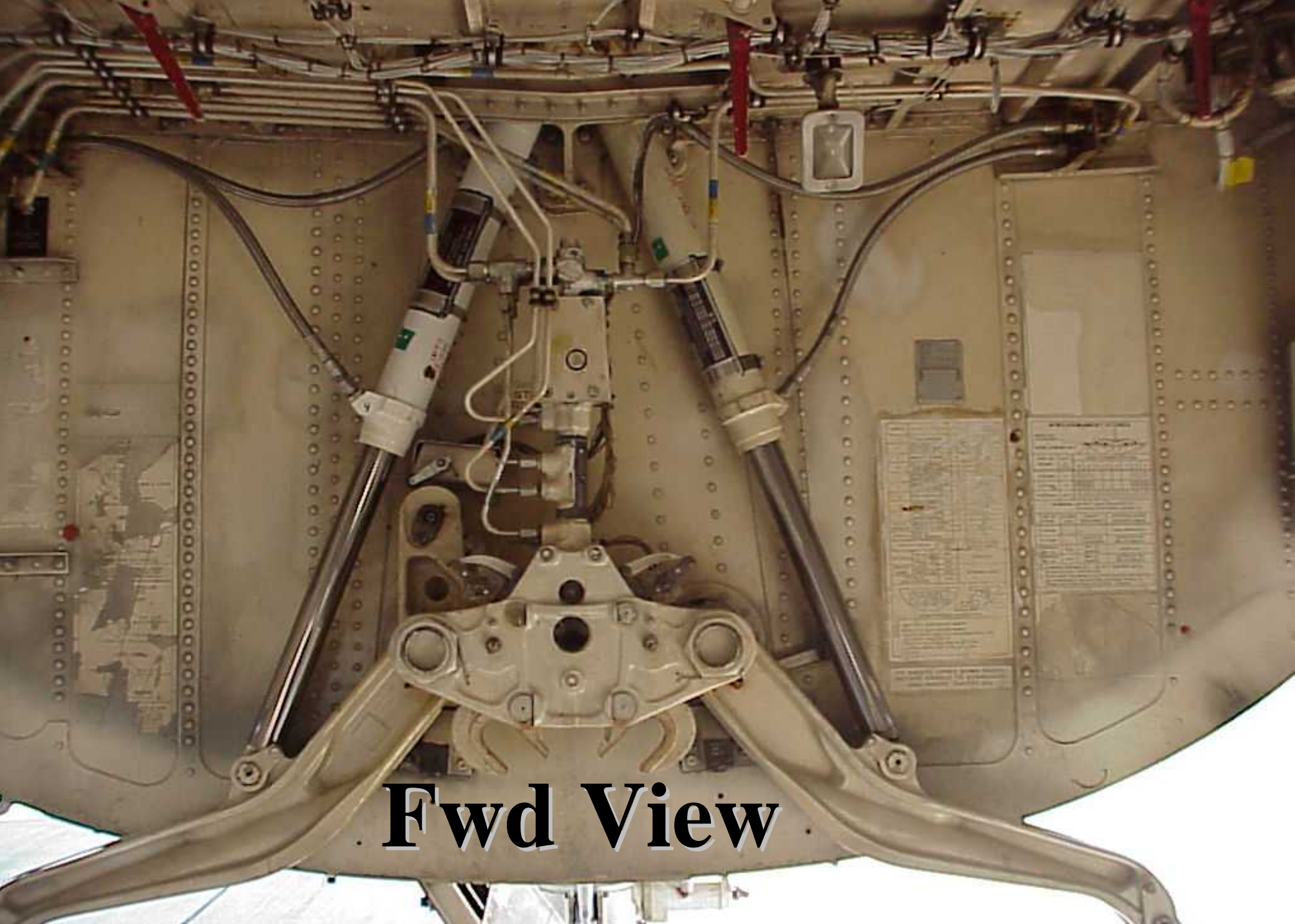
HVOF as a Hard Chrome Replacement



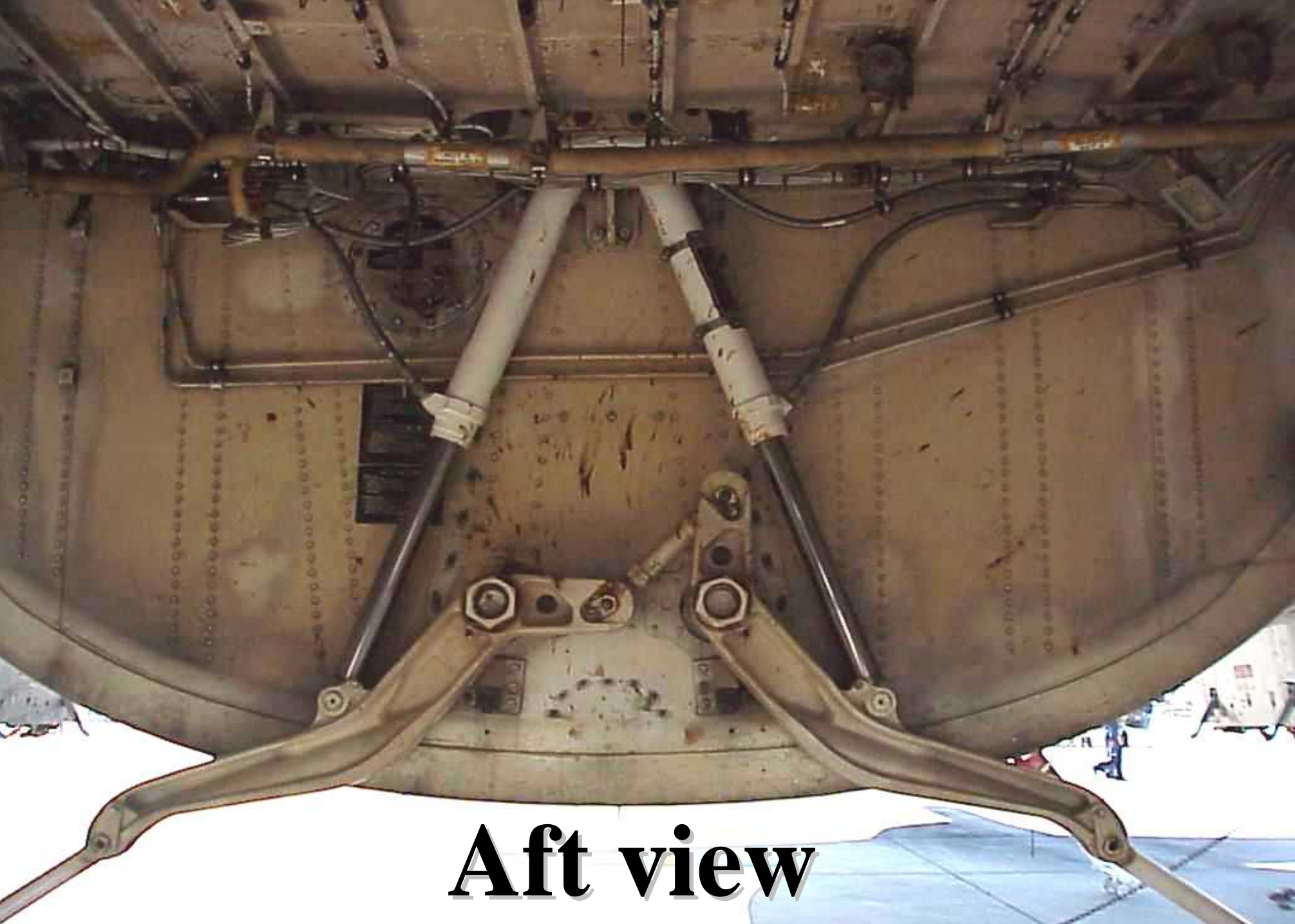
HVOF as a Hard Chrome Replacement

- **P-3 Bomb Bay Door Actuator Pistons coated, ground, & superfinished**
- **Four HVOF coated P-3 Bomb Bay Door Actuator Assemblies RFI and installed on VP-30 Aircraft BuNo 156510 July 2001**
- **91 Flight Hours on HVOF coated actuators (01 Feb 02)**
- **232 Flight Hours on HVOF coated actuators (05 Sept 02)**
- **704 Flight Hours on HVOF coated actuators (28 March 03)**
- **869 Flight Hours on HVOF coated actuators (24 Sept 03)**
- **1,154 Flight Hours on HVOF coated actuators (7 May 04)**
- **1,235 Flight Hours on HVOF coated actuators (9 July 04)**





Fwd View

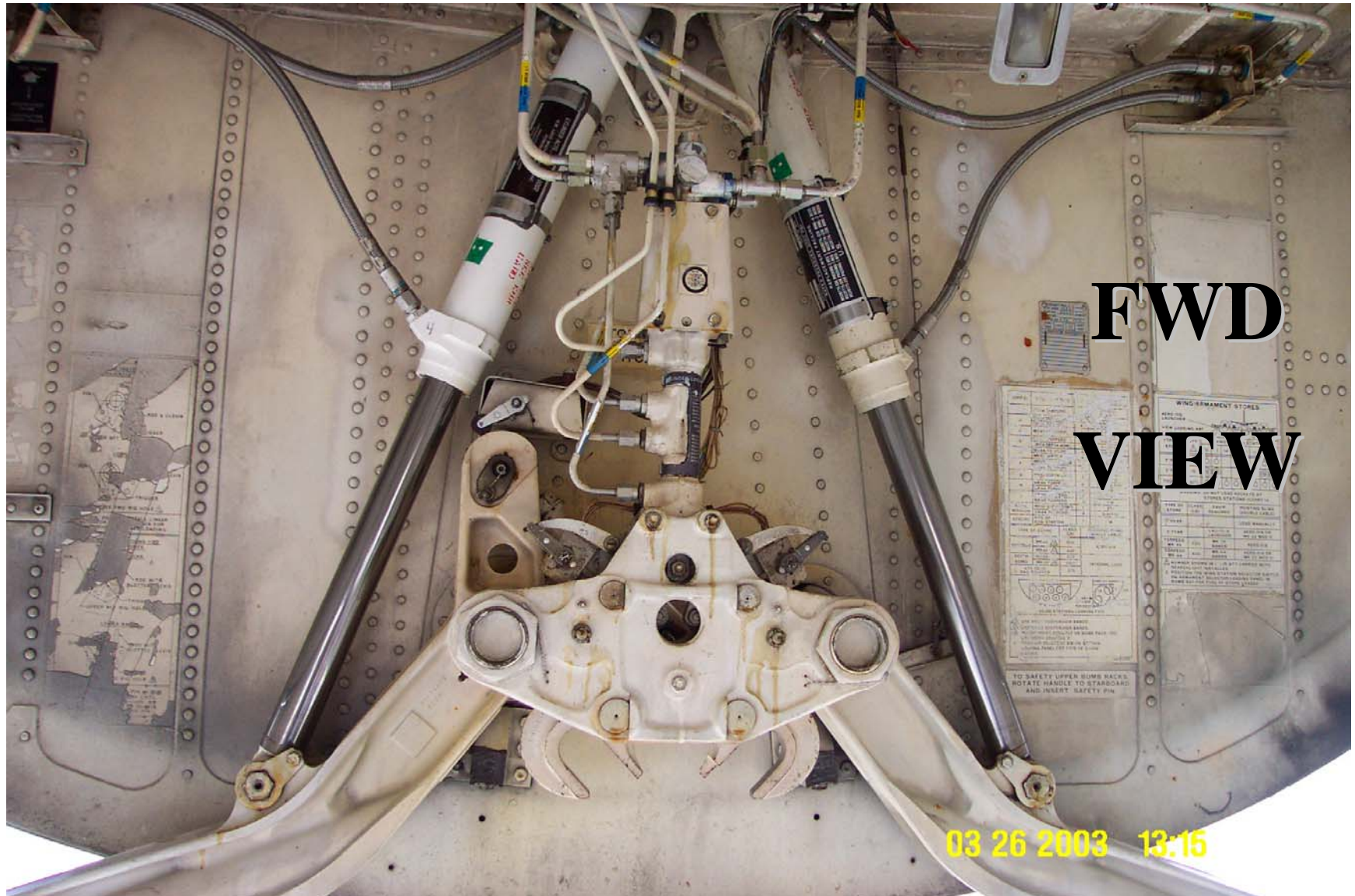


Aft view

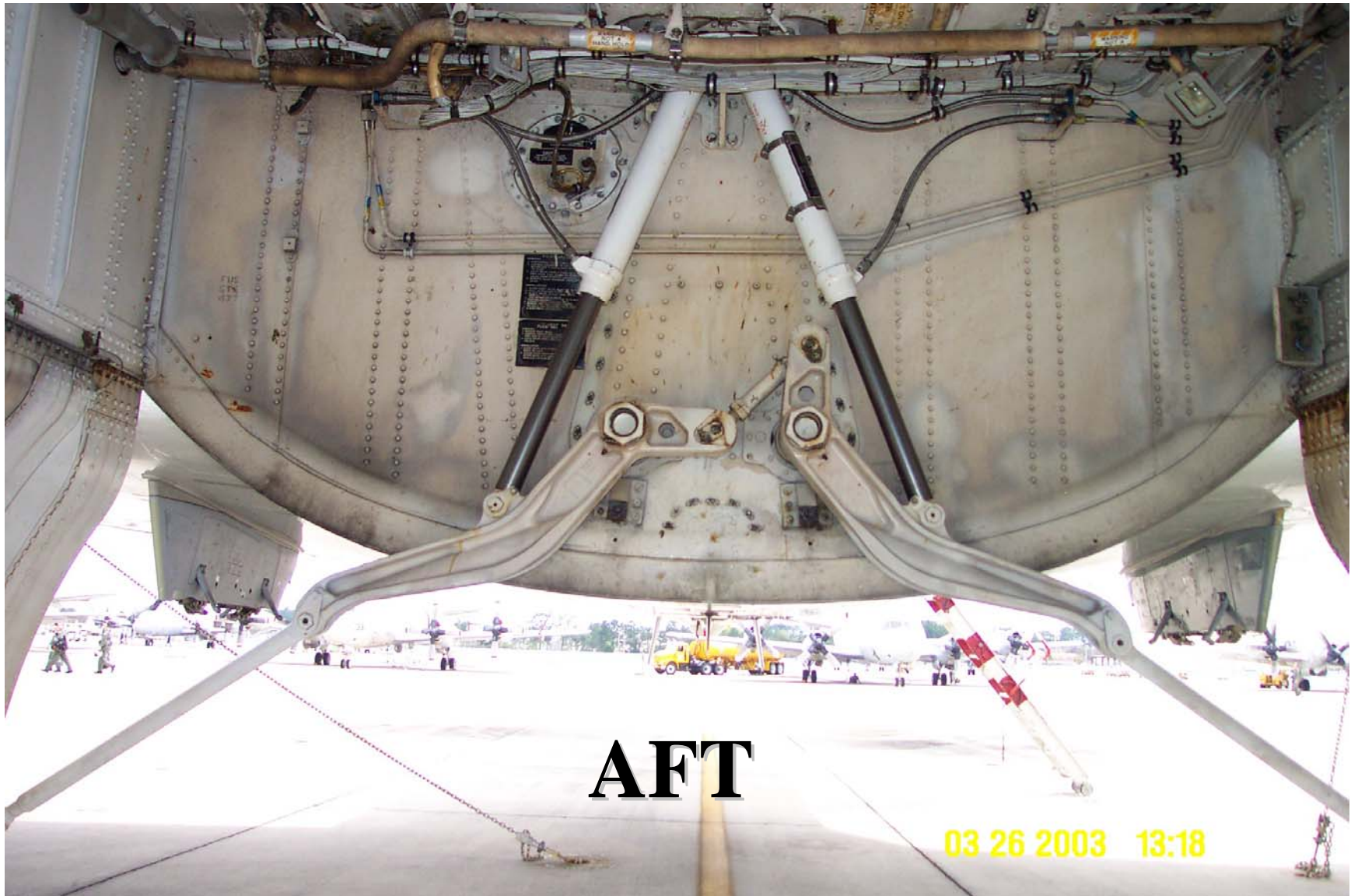
HVOF as a Hard Chrome Replacement



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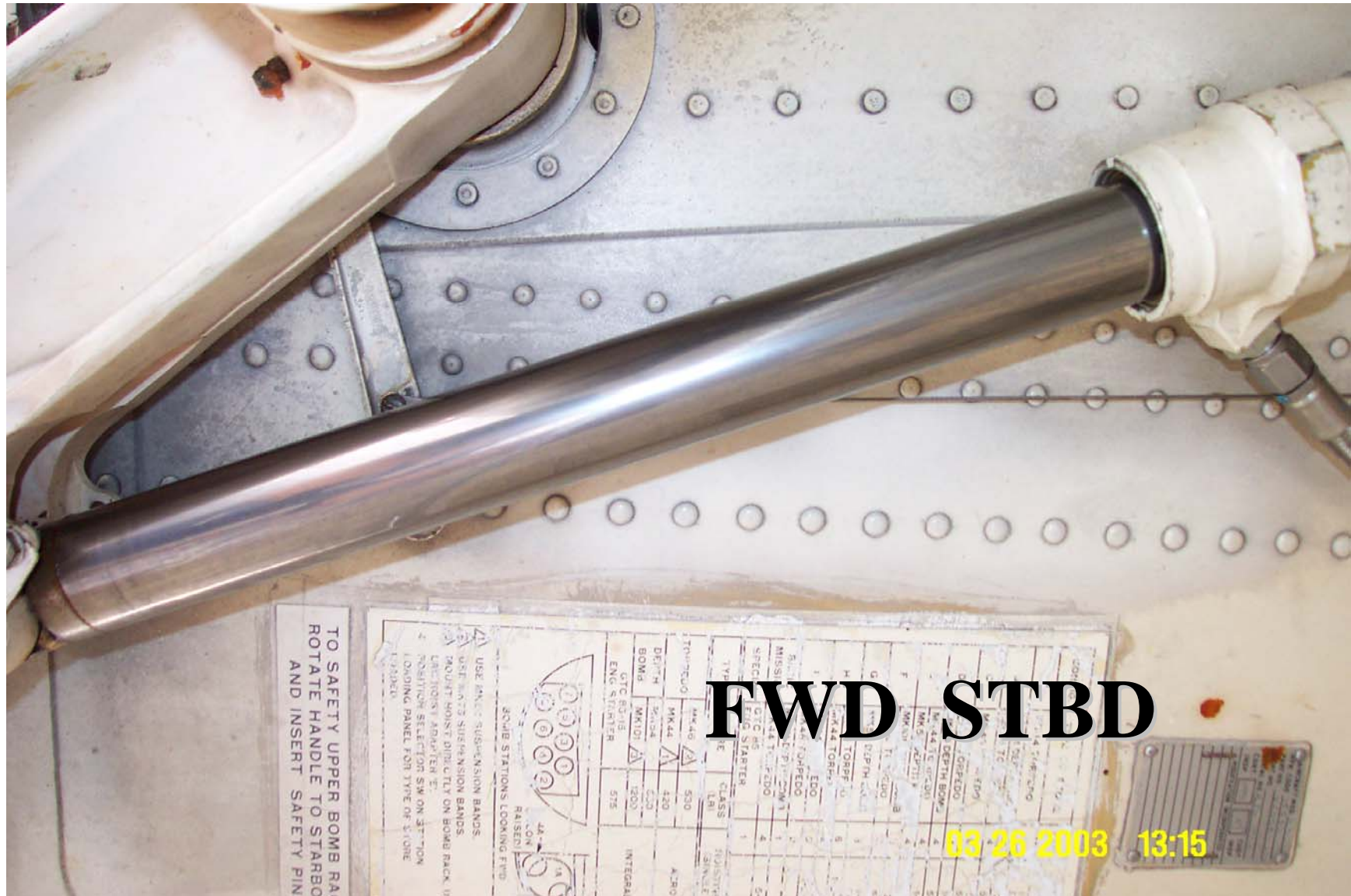
HVOF as a Hard Chrome Replacement



HVOF as a Hard Chrome Replacement

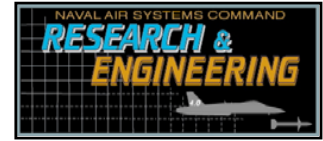


HVOF as a Hard Chrome Replacement





HVOF as a Hard Chrome Replacement



F/A-18 Horizontal Stabilator Piston Rod

P/N 3003130 (Vendor Code 93835) - Nat'l Water Lift

HVOF Coat short external end with WC/Co/Cr 86/10/4

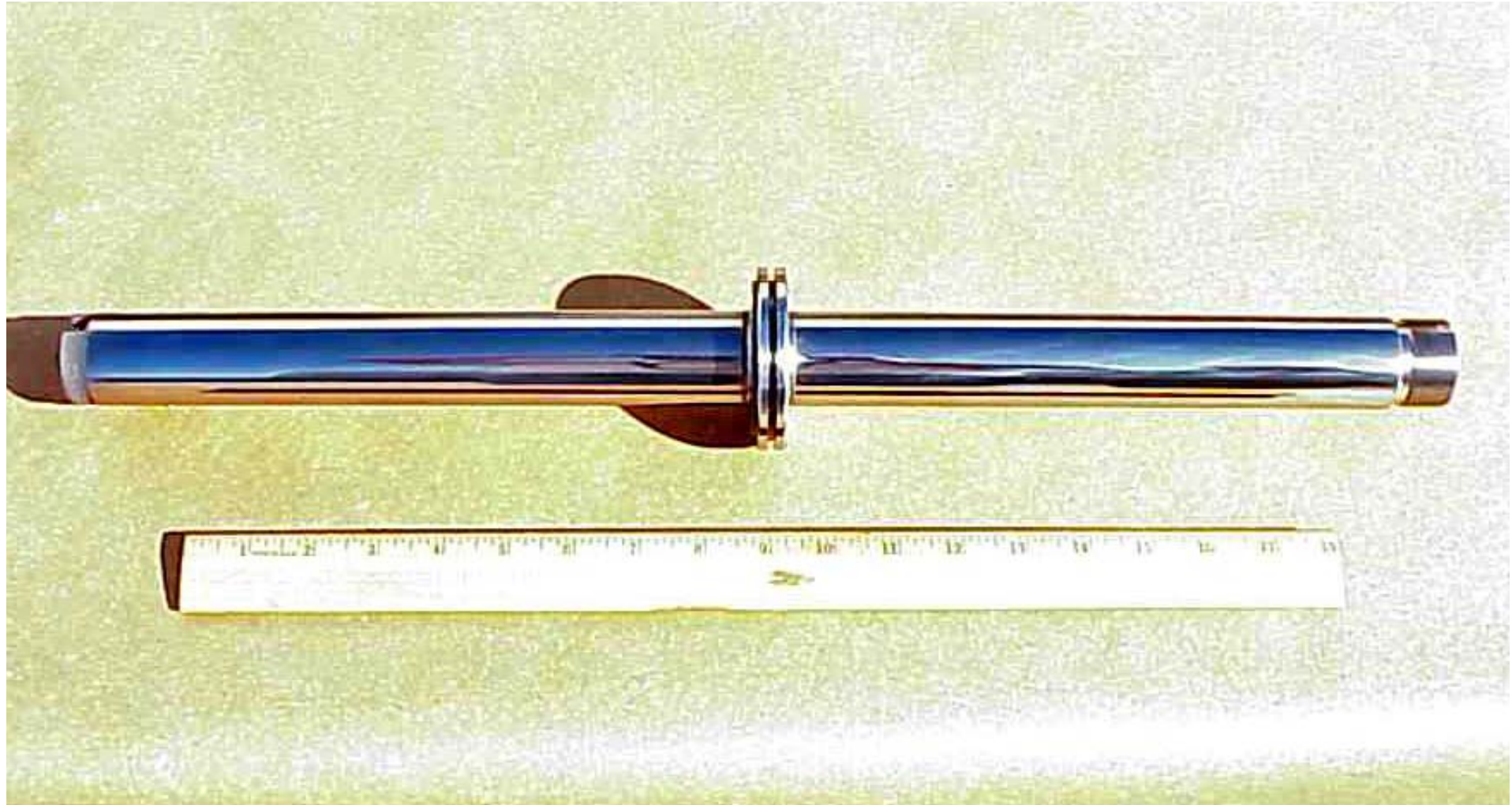
HVOF Coat longer internal end with WC/Co 83/17

Grind to 8 - 16 μ in Ra finish

Superfinish to ≤ 2 μ in Ra finish

**Shipped to PAX Lab for additional Hydraulic Actuator
seal compatibility testing on 15 Nov 02**

HVOF as a Hard Chrome Replacement

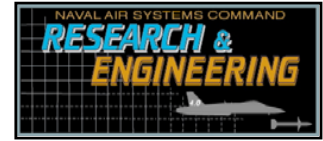


HVOF as a Hard Chrome Replacement





HVOF as a Hard Chrome Replacement



**F/A-18 Trailing Edge Flap (TEF) Actuator Piston Rod
P/N 303247-3 (Vendor Code 82106) - Parker Hannifin
HVOF Coat OD of Piston Rod with WC/Co/Cr 86/10/4**

Grind to 8 - 16 μ in Ra finish

Superfinish to ≤ 2 μ in Ra finish

**Shipped to NADEP NORIS for additional Hydraulic
Actuator seal compatibility testing on 20 Mar 03**

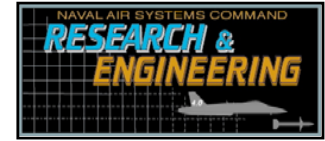
**Second F/A-18 TEF Actuator Piston Rod shipped to
NADEP NORIS 16 Sept 03 for build-up and then ship to
PAX for additional Hydraulic Actuator seal
compatibility testing**

HVOF as a Hard Chrome Replacement





HVOF as a Hard Chrome Replacement



Current Status of E-6A Main Landing Gear

**Two HVOF coated E-6A MLG Uplock Hook Shafts
installed 10 March 99 on A/C 164388**

4,936.5 Flight Hours (6/01/04) A/C completed

3,714 Landings (6/01/04) Mod in Waco, TX

**One HVOF coated E-6A MLG Uplock Hook Shaft
installed on Aircraft 162784 in Feb. 2000**

5,141 Flight Hours (6/01/04)

3,505 Landings (6/01/04)

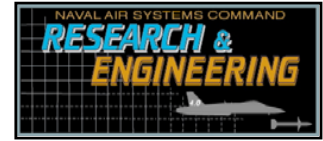
HVOF as a Hard Chrome Replacement

E-6A MLG Lock Hook Shaft P/N 9-45196





HVOF as a Hard Chrome Replacement



Current Status of HVOF Coated EA-6B Main Landing Gear Flight Clearance

MLG Collar and Piston coated Oct. 99

Components completed depot processing Dec. 99

Flight clearance requested Jan 00

Meeting at NAVAIR/Pax River 13 April 00

Obtained NAVAIR approval of data May 00

Flight clearance at AIR 4.3.3 waiting final approval

HVOF as a Hard Chrome Replacement

“NAVAIR ONLY” HVOF L.G. meeting 16 Nov 00

Flight clearance on-hold

NAVAIR presented 240KSI requirement for all landing gear fatigue tests at Dec 00 HCAT mtg. @ KSC. Not clear where this requirement came from.

NAVAIR & NRL meeting 29 Jan 01

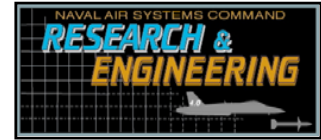
Large sample (2”-3” dia) testing discussed

NAVAIR (Eui Lee) to conduct testing

Flight clearance at AIR 4.3.3 waiting final approval



HVOF as a Hard Chrome Replacement



Meeting at BWI Sheraton 23 OCT 01

Large sample (2 1/4" OD dia) testing discussed

NAVAIR (Eui Lee) to test additional 30 large samples

Must test one NAVAIR large sample with 0.010" coating thickness at max. stress of 200 KSI, actual R-ratio of EA-6B MLG axle to be used during testing

Request to AIR 4.3.3 (Alysha Roerden) for R-ratio & max stress of EA-6B MLG inboard axle journal 23 Oct 01

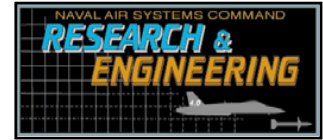
R-ratio & max. stress from AIR-4.3.3 Feb 02

(200 KSI @ R = -1)

Flight clearance at AIR 4.3.3 waiting final approval



HVOF as a Hard Chrome Replacement



Meeting at BWI Sheraton 23 OCT 2001

Large sample (2 1/4" OD dia) testing discussed

NAVAIR (Eui Lee) to test additional 30 large samples

Must test one NAVAIR large sample with 0.010" coating thickness at max. stress of 200 KSI, actual R-ratio of EA-6B MLG axle to be used during testing

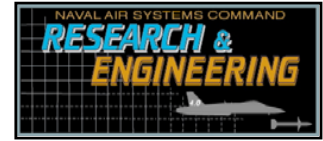
Jim Candela AIR-4.3.3 stated at the 23 Oct 01 meeting that he would accept data from either axial or bend tests

Request to AIR 4.3.3 (Alysha Roerden) for R-ratio & max stress of EA-6B MLG inboard axle journal 23 Oct 01

**R-ratio & max. stress rec'd from AIR-4.3.3 14 Feb 02
(200 KSI @ R = -1)**



HVOF as a Hard Chrome Replacement



**OEM analysis indicates max inboard journal stress for
0.010 inch thick coating is 180 KSI @ $R = +0.1$
and max inboard journal stress of 40 KSI for $R = -1$**

**Goodrich Corp., Cleveland, OH
Jack Pink (216) 429-4214, Neil Harris (216) 429-4202**

**Previously Cleveland Pneumatics - these are the people
who designed the EA-6B Landing Gear**

**EA-6B MLG alloy is 4330 V-mod
220-240 KSI UTS 180-185 KSI Yield Strength**

HVOF as a Hard Chrome Replacement

HCAT Landing Gear JTP test data for $R = +0.1$ testing of 0.003" thick coating up to 220 KSI; no spalling

Air Force A-10 NLG testing of 0.010" thick coating at $R = -0.33$ up to 260 KSI before spalling

Testing of NAVAIR large sample with 0.010" coating thickness at max. stress of 180 or 200 KSI, actual R-ratio of EA-6B MLG axle $R = +0.1$ is not necessary

NAVAIR & HCAT "big bar" tests confirmed that the stress/strain for spalling was essentially the same for both the small fatigue bar samples and the large tensile bars

AIR-4.3.3 (Candela) stated at the 23 Oct 01 meeting that he would accept data from either axial or bend tests

HVOF as a Hard Chrome Replacement

Dominant stress on the axle is bending

Bend testing done on HVOF coatings will provide more direct results than any axial testing

Axial (tension) testing on a bar does not represent the loading conditions on the axle journal

Air Force bend tests on actual A-10 NLG hardware concluded that HVOF applied WC/Co coatings 0.010" thick would remain intact at any stress level up to the yield strength of the substrate being tested

Air Force data at more severe condition of $R = -0.33$ shows 0.010" coating good up to 260 KSI

HVOF as a Hard Chrome Replacement

Meeting at PAX River on 19 August 2003

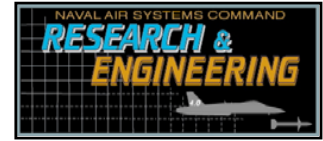
Discussion centered around A/F Bend Test Data. It was agreed that bend test data is more representative of the loading conditions for this application (axle journals).

OEM (Goodrich Corp. - previously Cleveland Pneumatics) presented a detailed stress analysis for the axle journals. Purpose to determine stress levels at bearing journals to aid in decision/evaluation of using HVOF on axle journals.

OEM analysis indicates max inboard journal stress for 0.010 inch thick coating is 180 KSI @ $R = +0.1$ and max inboard journal stress of 40 KSI for $R = -1$



HVOF as a Hard Chrome Replacement



Meeting at PAX River on 19 August 2003

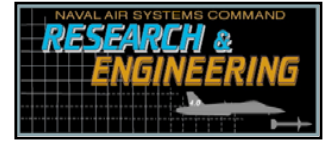
NAVAIR Structures (AIR-4.3.3.1) has given approval to move ahead with flight clearance request for HVOF coated Strut.

**Flight Clearance Message issued DTG
102001Z DEC 03**

HVOF coated Strut Assy re-inducted into Depot Landing Gear Shop for repeat of final pressure check and leak test prior to being issued as RFI to aircraft line (Feb 2004)



HVOF as a Hard Chrome Replacement



Aircraft 163395 identified

**HVOF coated MLG Strut Assy installed on
EA-6B Aircraft 163395 June 04**

Scheduled Completion Date - July 9, 2004

FIRST FLIGHT w/ HVOF strut 13 July 2004

Aircraft Sell Date is July 19, 2004

Aircraft to go to Whidbey Is.

HVOF as a Hard Chrome Replacement



This NAVAIR asset has a replacement cost of \$315,858 and has been collecting dust for four years. Based on stress levels provided by the OEM that designed the gear and the successful AF tests that simulated actual bending stress application in service, the test flying of this EA-6B gear is considered to have minimal risk. Flight clearance has been issued 10 Dec 2003.

HVOF as a Hard Chrome Replacement



HVOF coated R/H EA-6B MLG Strut Assy.

P/N 1707B00-02 S/N BFG 5008

HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.
P/N 1707B00-02
S/N BFG 5008
Aircraft
163395**

HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.**

P/N 1707B00-02

S/N BFG 5008

**Aircraft
163395**

HVOF as a Hard Chrome Replacement



HVOF coated

EA-6B MLG

Strut Assy.

P/N 1707B00-02

S/N BFG 5008

Aircraft

163395

HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.
P/N 1707B00-02
S/N BFG 5008
Aircraft
163395
July 13, 2004
09:34 a.m.**

HVOF as a Hard Chrome Replacement



HVOF coated

EA-6B MLG

Strut Assy.

P/N 1707B00-02

S/N BFG 5008

Aircraft

163395

July 13, 2004

09:34 a.m.

HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.
P/N 1707B00-02
S/N BFG 5008
Aircraft
163395
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HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.
P/N 1707B00-02
S/N BFG 5008
Aircraft
163395
July 13, 2004**

HVOF as a Hard Chrome Replacement



**HVOF coated
EA-6B MLG
Strut Assy.**

P/N 1707B00-02

S/N BFG 5008

Aircraft

163395

July 13, 2004

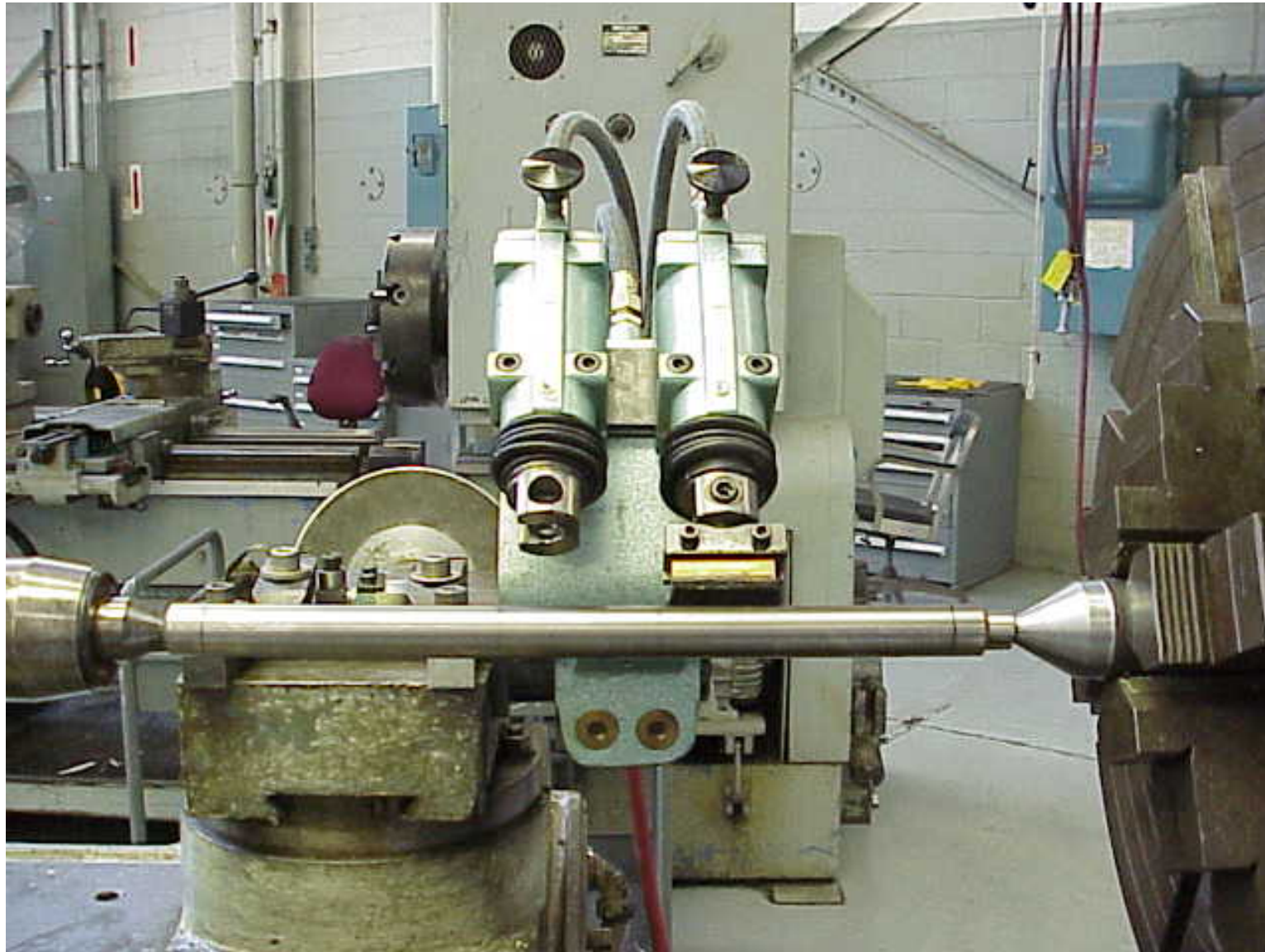
HCAT Hydraulic Actuator

Joint Test Protocol

Part II, Phase 1

Functional Rod/Seal Testing

HVOF as a Hard Chrome Replacement



**HCAT
Hydraulic
Actuator
JTP
Part II
Phase 1
1" dia.
Test rod**

**Superfinished
at
NADEP JAX**

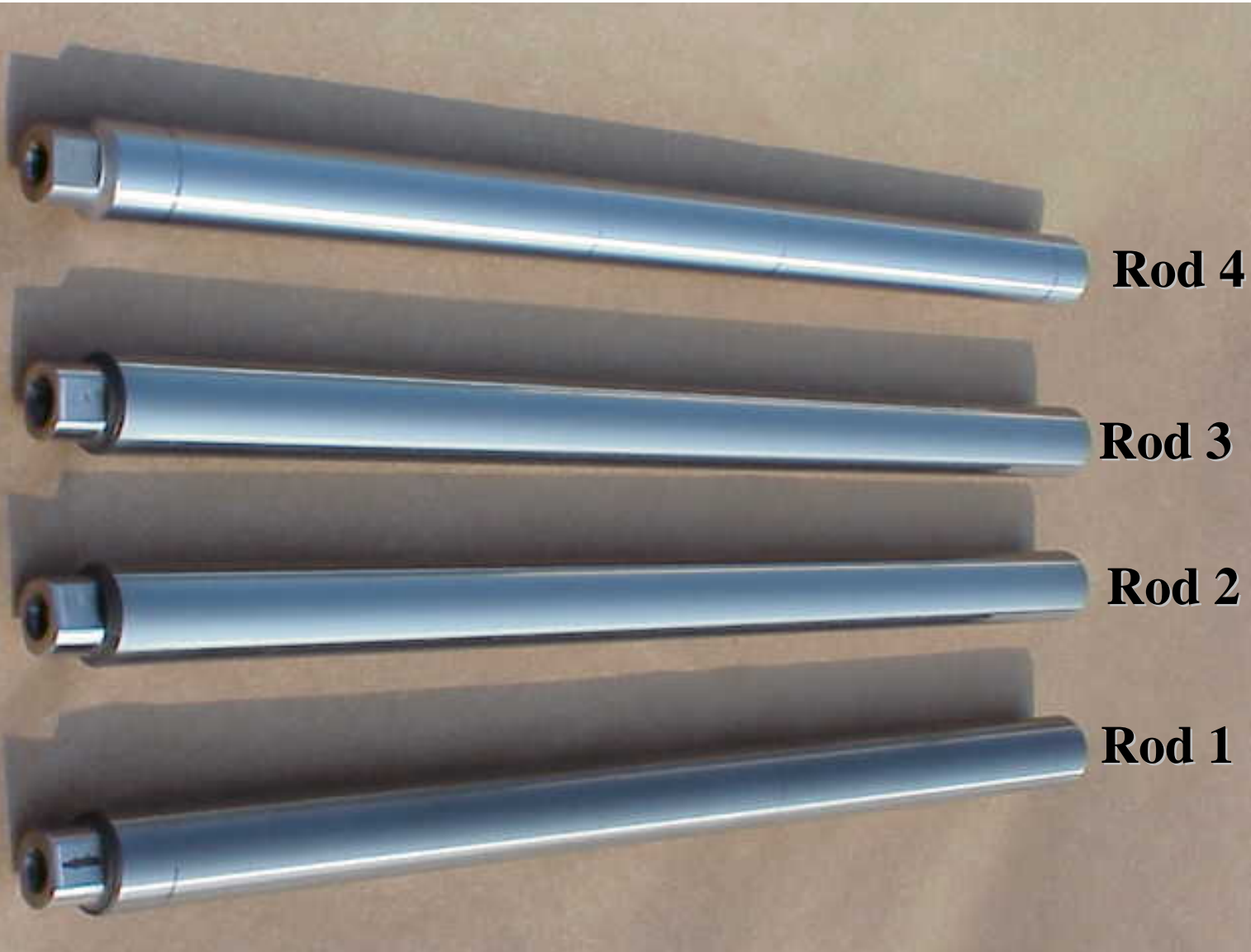
HVOF as a Hard Chrome Replacement



**HCAT
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JTP
Part II
Phase 1
1" dia.
Test rod**

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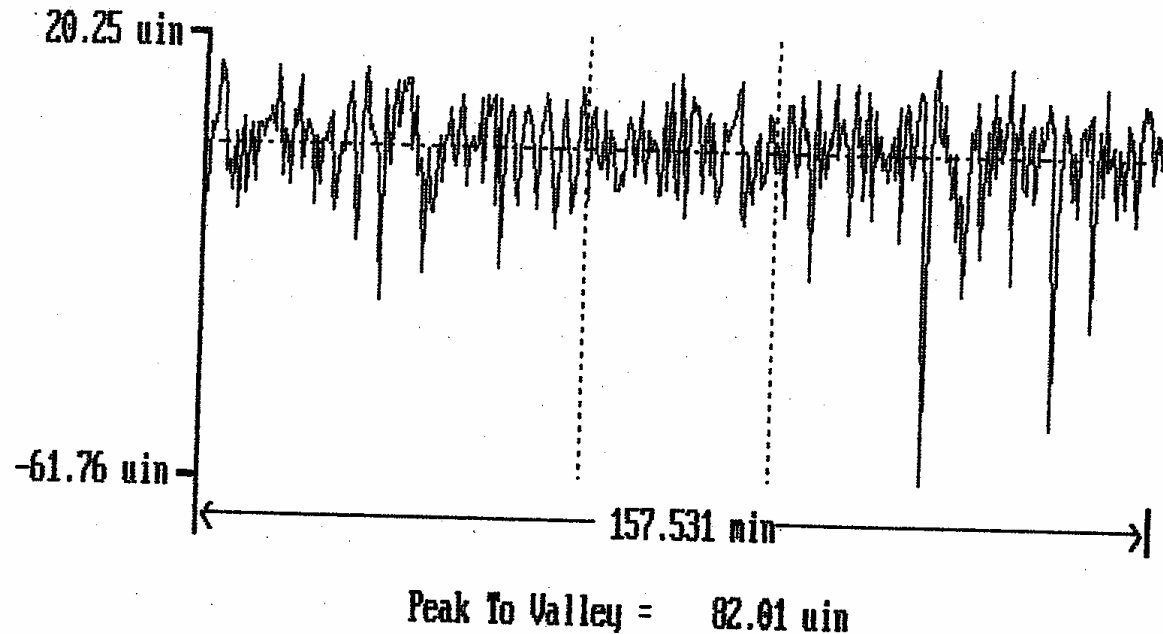
HVOF as a Hard Chrome Replacement



**HCAT
Hydraulic
Actuator
JTP
Part II
Phase 1
1" dia.
Test rod**

**Superfinished
at
NADEP JAX**

HVOF as a Hard Chrome Replacement



Rtm =	58.50 uin	Lo =	157.531 min	Ra =	6.46 uin
Rpm =	17.35 uin	Rp =	20.25 uin	Rq =	9.00 uin
Ry =	82.01 uin	Rv =	61.76 uin	Rsk =	-1.9
Rt1 =	48.72 uin	Rt =	82.01 uin	Rku =	10.9
Rt2 =	49.00 uin			Delq =	2.65 Deg
Rt3 =	32.39 uin	SLOPE =	.05 Deg	Lamq =	1.222 min
Rt4 =	82.01 uin			S =	633.54 uin
Rt5 =	80.39 uin			Sm =	1.200 min
				R3z =	37.86 uin
				R31 =	66.38 min

Rod 1

Measurements by
Bob Paterson
Supfina, Inc.

Taylor-Hobson

Cut Off – 0.030 In.

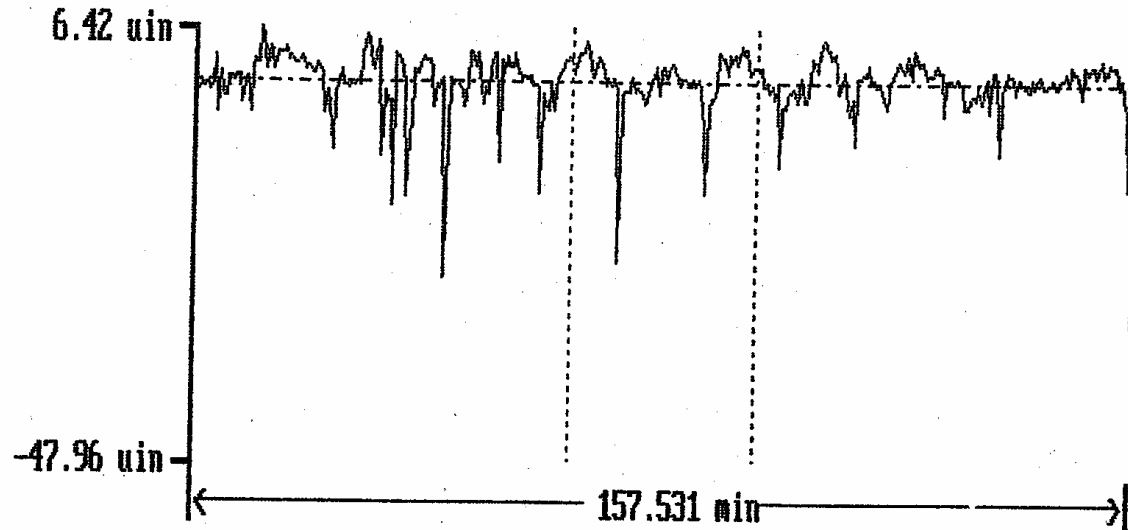
WC/Co/Cr 86/10/4

Ground to 4 – 6 Ra

320 grit diamond

As Ground

HVOF as a Hard Chrome Replacement



Peak To Valley = 54.38 uin

Rtm = 36.23 uin	Lo = 157.531 min	Ra = 2.31 uin
Rpm = 5.06 uin	Rp = 6.42 uin	Rq = 4.15 uin
Ry = 51.11 uin	Rv = 47.96 uin	Rsk = -4.7
Rt1 = 23.34 uin	Rt = 54.38 uin	Rku = 39.5
Rt2 = 46.67 uin		Delq = 1.22 Deg
Rt3 = 27.41 uin	SLOPE = .05 Deg	Lamq = 1.228 min
Rt4 = 32.62 uin		S = 915.11 uin
Rt5 = 51.11 uin		Sm = 2.346 min
		R3z = 15.36 uin
		R3y = 25.65 uin

Rod 2

Measurements by
Bob Paterson
Supfina, Inc.

Taylor-Hobson

Cut Off – 0.030 In.

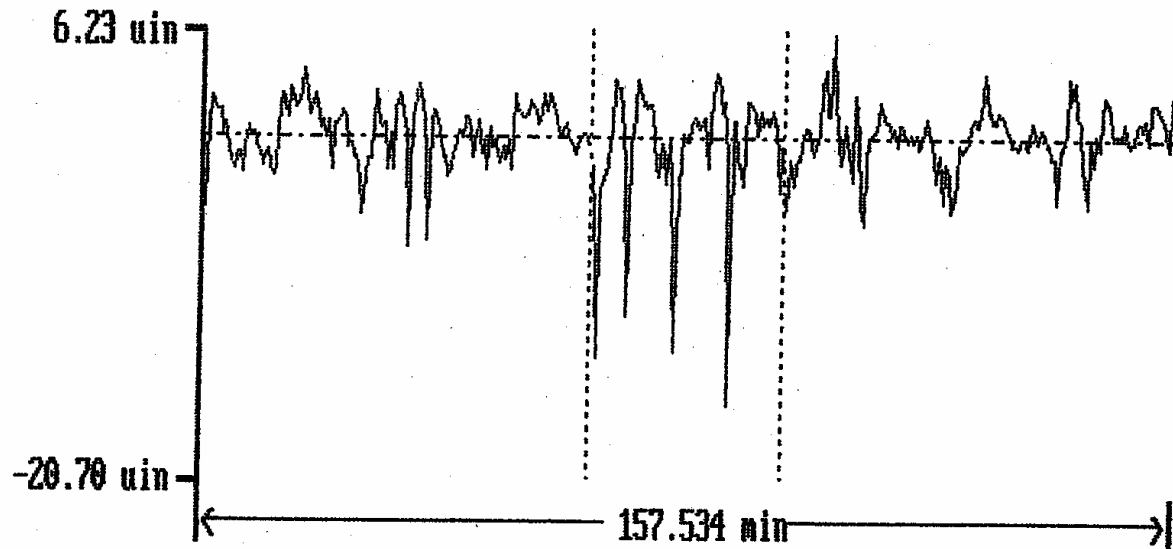
WC/Co/Cr 86/10/4

Ground to 20 – 22 Ra

120 grit diamond

Superfinished at
NADEP JAX to 2 Ra

HVOF as a Hard Chrome Replacement



Peak To Valley = 26.92 uin

Rtm = 14.22 uin	Lo = 157.534 min	Ra = 1.49 uin
Rpm = 4.60 uin	Rp = 6.23 uin	Rq = 2.18 uin
Rj = 26.25 uin	Rv = 20.70 uin	Rsk = -2.2
Rt1 = 13.73 uin	Rt = 26.92 uin	Rku = 16.9
Rt2 = 9.85 uin		Delq = .51 Deg
Rt3 = 26.25 uin	SLOPE = .04 Deg	Lamq = 1.537 min
Rt4 = 12.67 uin		S = 877.46 uin
Rt5 = 8.60 uin		Sm = 2.320 min
		R3z = 9.44 uin
		R3u = 16.77 uin

Rod 3

Measurements by
Bob Paterson
Supfina, Inc.

Taylor-Hobson

Cut Off – 0.030 In.

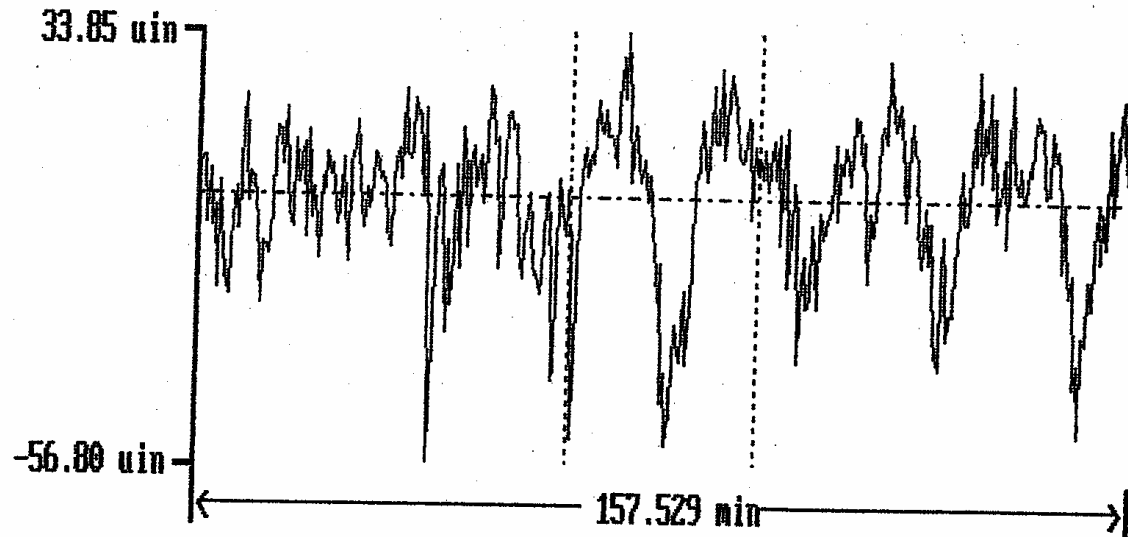
WC/Co/Cr 86/10/4

Ground to 8 – 10 Ra

220 grit diamond

Superfinished at
NADEP JAX to 2 Ra

HVOF as a Hard Chrome Replacement



Peak To Valley = 90.65 uin

Rtm = 75.29 uin	Lo = 157.529 min	Ra = 12.27 uin
Rpm = 28.12 uin	Rp = 33.85 uin	Rq = 15.75 uin
Ry = 90.32 uin	Rv = 56.80 uin	Rsk = -1.0
Rt1 = 53.29 uin	Rt = 90.65 uin	Rku = 3.8
Rt2 = 80.17 uin		Delq = 2.81 Deg
Rt3 = 90.32 uin	SLOPE = .05 Deg	Lamq = 2.013 min
Rt4 = 75.43 uin		S = 605.34 uin
Rt5 = 77.25 uin		Sm = 2.004 min
		R3z = 58.90 uin
		R3y = 82.51 uin

Rod 4

Measurements by
Bob Paterson
Supfina, Inc.

Taylor-Hobson

Cut Off – 0.030 In.

Chrome plated at
NADEP JAX

Ground to 12 – 15 Ra

60 grit Al₂O₃

As Ground

HVOF as a Hard Chrome Replacement



Any Questions?